

PSR Report 2708

# **PRELIMINARY DESIGN OF THE PORTABLE THERMAL NONDESTRUCTIVE EVALUATION SYSTEM**

**Item 0001AA**

A. Daniels

May 1997

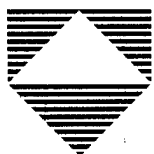
Contract No. N68335-97-C-0203

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## **Section 1**

### **INTRODUCTION**

The primary objective of this Phase I is to establish the usefulness of the Thermal Nondestructive Evaluation (TNDE) method as a non-contact, large area Nondestructive Inspection (NDI) technique for the evaluation of in-fleet composite rocket motor cases/airframes. The method consists of subjecting the specimen surface to a thermal excitation and dynamically collecting the heat flow pattern within the material by means of infrared images in frames in a time sequence. Thermal discontinuities related to the presence of subsurface defects will appear in time according to their depth. The Phase I work plan will be oriented towards the design of a portable, high speed pulsed thermal nondestructive testing (TNDT) mini-workstation.

In this initial NDE report, Pacific-Sierra Research Corporation (PSR) performs a detail study with the goal of determining the required specifications and characteristics of the TNDE laboratory testbed Thermal Imaging System (TIS), to demonstrate the feasibility of the thermal technique. These include: Field-of-regard, sensitivity, resolution, frame time, data rate, spectral response, detector type, power requirements, and speed.

This report consists of four (4) sections. The first section is this introduction; it describes the contents of this Phase I initial report. Section 2 describes the required specifications and characteristics of a portable TNDE mini-workstation for NDI and testing of aerospace and industrial materials and structures. It also provides the preliminary design of a TNDE portable system for Phase II. Section 3 provides a detail description of two existing NDE IR workstations with acceptable features to satisfy the Phase I demo requirements. The remarks and conclusions are presented in Sec. 4. The reader should put special attention to this section, because it emphasizes the advantages and disadvantages of the thermographic systems presented in the previous sections. It also explains which atmospheric operating wavelength band should be selected for this particular TNDE application.

## Section 2

### THERMAL NDE SYSTEM ANALYSIS REQUIREMENTS AND SPECIFICATIONS

The theoretical and experimental analysis in this Phase I work will be emphasized towards the design of a portable, high speed, TNDE mini-workstation.

The specifications and characteristics of this portable thermographic equipment are very important for (TNDE) applications. The difference in temperature between the sound material and the damage areas are usually very small (i.e., tenths of a degree Kelvin), so the IR camera must have an excellent thermal sensitivity to locate and quantify such small contrast in the IR images. High spatial resolution is also required to resolve millimeter sized defects while imaging large areas. Once the required information is obtained, the infrared data must be processed to enhance the image quality and thus increase the probability of detection.

The following calculations are performed to evaluate a preliminary design of a high speed IR system. This development specifies the required characteristics needed for the Phase I TNDE laboratory testbed system and examines the feasibility of the thermal technique. This analysis also produces the basis for the design of a portable prototype system that is to be fully developed as part of the Phase II effort. The resulting system specifications are:

- **Detector**

The detector-dewar assembly is an opto-electronic device sensitive to radiation in the 7.7-to 10.5- $\mu\text{m}$  spectral region. The detector assembly includes a  $288 \times 4$  IR Charge-Coupled Device (CCD) two-dimensional array of Photovoltaic MCT detector elements. A silicon processor with time-delay-integration (TDI) and multiplexing are housed within the assembly. The signal-to-noise ratio is improved by the TDI.

Detector pitch:  $25 \mu\text{m} \times 28 \mu\text{m}$ .

Array size:  $383 \mu\text{m}$  (scanning direction  $x_{\text{total}}$ )  $\times$   $8064 \mu\text{m}$  (vertical direction  $y_{\text{total}}$ ).

D-Star:  $D^* = 1.5 \times 10^{11} \text{ cm} \sqrt{\text{Hz}} / \text{Watt}$ .

- **Desired Characteristics**

Clear diameter of the lens:  $D_{\text{opt}} = 30 \text{ mm}$ .

Field-of-view:  $\text{FOV} = 30^\circ H \times 15^\circ V = 0.52 \text{ rad } H \times 0.26 \text{ rad } V$ .

Frame time:  $T_{\text{frame}} = 2 \text{ msec}$ .

The required focal length of the lens is determined by

$$f = \frac{y_{total}}{VFOV} = \frac{8064 \times 10^{-3}}{0.26} = 30 \text{ mm} .$$

The F-number is given by

$$F_{\#} = \frac{f}{D_{opt}} = 1 .$$

The necessity of such a small F-number is twofold: Provides us with high speed optics (i.e., more flux collected), improving the thermal sensitivity of the system; makes the diffraction limit of the system smaller than the detector pitch. If using a  $10.5 \mu\text{m}$  wavelength,  $D_{bar} = 2.44\lambda F_{\#} = 24.3 \mu\text{m}$ .

The resolution or instantaneous field-of-view (IFOV) in both directions are

$$VIFOV = \frac{y_{det}}{f} = \frac{28 \times 10^{-4}}{3} = 0.93 \text{ mrad} ,$$

$$HIFOV = \frac{X_{det}}{f} = \frac{25 \times 10^{-4}}{3} = 0.83 \text{ mrad} .$$

If we evaluate a sample which is at 304.8 mm distance away from the camera, the spatial resolution in the scanning direction will be 0.24 mm. Most of the subsurface defects are millimeters to centimeters in size. The design of the system is such that each scan covers the full VFOV. Therefore, the frame time is equal to the line time. This reduces the mechanical complexity and size of the IR camera.

The scan velocity is given by

$$v_{scan} = \frac{HFOV}{T_{frame}} = \frac{0.52}{2 \times 10^{-3}} = 260 \text{ rad/sec} ,$$

therefore, the dwell time can be calculated as

$$\tau_{dwell} = \frac{HIFOV}{v_{scan}} = \frac{0.83 \times 10^{-3}}{260} = 3.2 \mu\text{sec} ,$$

and the electronic bandwidth is given by

$$\Delta f = \frac{1}{2\tau_{dwell}} = 156.6 \text{ KHz} .$$

To keep the size of the camera small, a high-performance polygonal scanner will be used. The scanner rotational speed may be expressed as

$$\omega_{polygon} = \frac{60W}{N} ,$$

where  $\omega_{polygon}$  is the velocity of the motor of the polygon in rpm, W is the number of desired frames per second (i.e., 500  $\frac{\text{frames}}{\text{sec}}$ ), and N is the number of facets of the polygon. If the velocity of the motor is 5000 rpm, a polygon with 6 facets is needed.

#### • Thermal Sensitivity

Measurement of the Noise Equivalent Temperature Difference (NETD) calibrates the thermal sensitivity of the imager system. The NETD is calculated by

$$NETD = \frac{4}{\pi} \frac{F_{\#} \sqrt{\Delta f}}{D^* D_{opt} \alpha \left( \frac{\partial L}{\partial T} \right)} .$$

where  $\alpha$  is the angular subtense and  $\frac{\partial L}{\partial T}$  is the derivative of the radiance L with respect to the temperature in degrees Kelvin. At room temperature the thermal sensitivity is 0.014 °K. This thermal sensitivity was calculated for the long wave infrared (LWIR) spectral band.

#### • Portable Thermal Source

A pulse heat source using a single linear xenon lamp with a parabolic reflector that directs the lamp energy to the desired target will be investigated. This lamp can output approximately 5.5 KJoules of energy. The power and geometry of the thermal stimulation device determines rate of inspection. As an example, if an irradiance of one Kjoule/m<sup>2</sup> is used, the required power to inspect an area of 1m<sup>2</sup> every 10 seconds will be 100 Watts. In this case, two Lithium ion battery packs connected in series from ID



Technology model NP-L40 can be used. This portable power supply will provide 100 Watt-hours and weights only 1.6 pounds.

Utilization of a single thermal pulse for the stimulation of the workpiece is very practical since all frequencies are tested simultaneously (i.e., flat frequency spectrum of a Dirac pulse), but there is reduced sensitivity. A better sensitivity is achieved when a periodic thermal cycle (e.g., a repetition rate of ten pulses per 100 seconds) of the specimen is used. In this case, individual frequencies can be tested separately. Both approaches will be investigated.

A more detailed design of this portable system will be provided as part of the optional Phase I task.

### **Section 3**

## **EXISTING NDT INFRARED EQUIPMENT**

### **PHASE I REQUIREMENTS**

PSR has identified two TNDE workstations: Thermal Imager Processor (TIP) from Bales Scientific Inc. (BSI) and Echo-Therm from Thermal Wave Imaging (TWI). Both systems comply with many of the required specifications of Section 2. However, these systems are not portable and they are mainly used for laboratory measurements and research purposes. Therefore, they will be used only to establish the usefulness of the TNDE method. PSR will use one or both existing workstations to collect data and prove feasibility. This approach will provide a significant cost savings in the analysis of thermographic data at this stage of the project. Based on these results, PSR will develop a NDT portable system with the appropriate characteristics in Phase II.

#### **3.1 THERMAL IMAGING PROCESSOR (TIP)**

The TIP system is comprised of a high resolution IR camera, a spectral hood that contains the illumination source and serves as the IR camera mount, and the TIP computer. A photograph of the Bales Scientific commercial TIP NDT workstation is shown in Fig. 1.

The IR camera is a scanning system with 600 optical lines in a 30° horizontal field of view (HFOV). It is able to resolve millimeter-size defects while imaging the total surface of the specular hood (i.e.,  $1,742 \text{ cm}^2$ ). The pulse heat source consists of four linear xenon lamps. Each lamp outputs a maximum of 5.5 *KJoules* of energy pulse (i.e., 22 *KJoules* total output) in a 4 *msec*. Each flash lamp has a pulse forming network (PFN) comprised of low inductance capacitance and a high "Q" inductor. One power supply charges and regulates all four PFN's simultaneously. Each individual lamp has a double parabolic reflector to direct the flash lamp energy to the specimen being tested. The flashlamps are programmable to assure a perfect synchronization with the IR system. The TIP computer includes the IR camera interface with an inline frame buffer which allows fast IR image acquisition. The specification and features of the TIP are listed as follows:

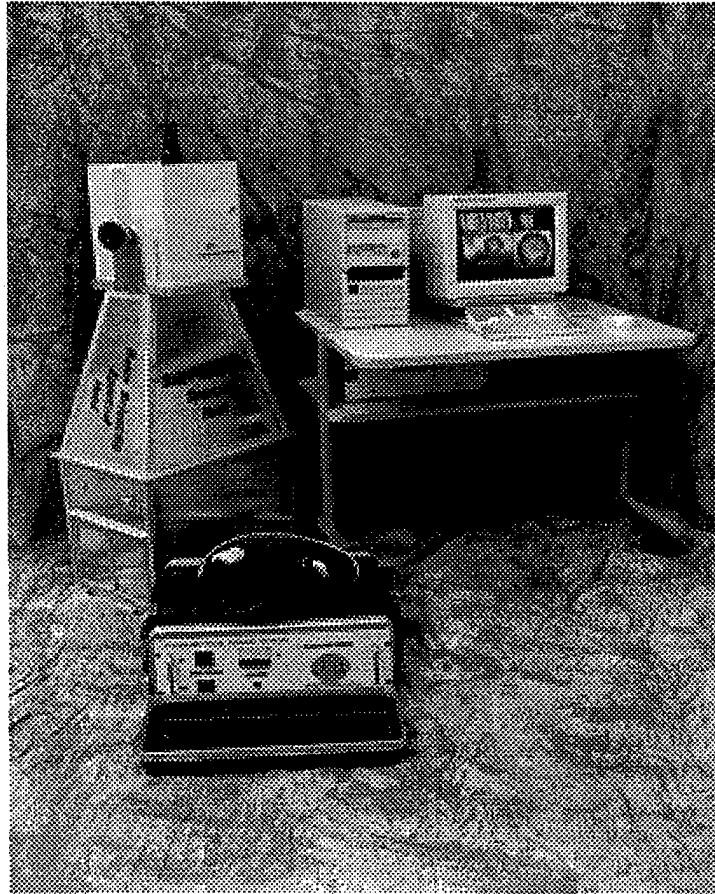


Figure 1. Bales scientific commercial TIP NDT workstation

Optical and Image Features:

- |  |  |
|--|--|
| 1. Detector angular subtends                       | 1.2 Milliradians with a 30° FOV<br>(Instantaneous field of view)     |
| 2. Field of view<br>(With continuous optical zoom) | 10° to 30° horizontal<br>5° to 20° vertical                          |
| 3. Spatial resolution                              | 600 optical lines at 30° FOV (50% modulation)                        |
| 4. Focus   | Automatic and manual override<br>(10cm to infinity focal range)      |
| 5. Optical frame cycle rate                        | Programmable (1,800 to 7,200 lines per second)                       |
| 6. Line scan mode                                  | 550 $\mu$ sec per line (included in NDT pkg.)                        |
| 7. Temperature range                               | 0° to 200° Celsius in 0.05 °C increments<br>(other ranges available) |

8. Minimum detectable temperature	0.05 °C at 35 °C
9. Spectral response	3-5, 8-12, 2-12 Microns (3-5 and 8-12 dual band optional)
10. Detector cooler type	LN <sub>2</sub> (linear drive cryocooler available)
11. Detector type	MCT (linear array optional)
12. Input power	150 Watts

#### Computer and Display Features:

1. Pentium system with 12 Mbytes RAM
2. UNIX operating system with X windows user interface
3. Compact keyboard with over 40 labeled function keys and separate mouse
4. 15" Color multi-frequency monitor
5. 1024 × 768 video resolution with 256 colors and/or shades of gray
6. The display and computer require 110 W and 250 W of power respectively

#### Software and Image Processing Features:

1. Pop-up menus using keyboard and/or mouse inputs
2. High precision pixel temperature measurement
3. Shapes library includes: circles, ovals, and user defined polygons
4. Math library includes: temperature measurement with high, low, avg., standard deviation, multi-point emissivity correction, shape and image histograms
5. Real-time image subtraction using live or stored images (for reference)
6. Up to 16 user defined windows displayed simultaneously with individual optical zoom and FOV
7. Images can be simultaneously displayed in color, gray, reverse gray, and real-time image subtraction modes
8. 12 Bit (1:4096) dynamic range and temperature resolution
9. Continuous temperature calibration via internal blackbodies traceable to NIST
10. Image storage and retrieval from HDD, floppy, and optical disk drives (including subject, time, and date stamp)
11. NDT analysis package (optional)

Nondestructive Testing Analysis Package Includes:

1. Thermal stimulus synchronization
2. Programmable image sequence and time delay between frames
3. Image sequence averaging and editing
4. Image addition, subtraction, biasing, and filtering
5. Line scan mode
6. Horizontal, vertical, and complete image profiles

Options:

1. color graphics printer
2. Rewritable SCSI optical laser drive - external 1.2 GB, 5.25" media
3. 21" .28 dot pitch RGB monitor
4. NDT analysis package
5. Software development package and network software
6. Thermal stimulus package

**3.2 ECHO-THERM**

Echo-Therm is an integrated system for IR NDE of substrate defects. It is fully digital and includes PCI-based image acquisition hardware; a Windows-based software program for data analysis; flashlamps and optics designed to provide maximum uniformity, minimum afterglow and short duration; a programmable power supply; and a Pentium computer. The system is compatible with the Galileo configurable IR camera from Amber. Echo-Therm features are listed as follows:

Windows software for real time control and analysis:

1. Capture up to 20 gated image sums
2. Continuous capture of high speed data
3. Dynamic histogram analysis
4. Temperature-time plotting
5. Statistical analysis of pixel data
6. 3-D perspective plotting
7. Automatic image compression and scaling
8. Image convolution, scaling, and rotation
9. Operates under Microsoft Windows 3.11

PC plug-in card for real-time image acquisition

1. Accepts 12-bit RS-422 digital data
2. Controls flash heat sources
3. Accepts high speed digital data

Flashlamps and accessories

1. Linear xenon flashlamps
2. Parabolic reflector with UV shield
3. Forced air cooling housing
4. Programmable power supply
5. Sequential charge controller
6. 110/220 VAC, 15 Amp operation

The Galileo IR camera is a modular FLIR sensor featuring selectable frame rates and simultaneous pixel integration, or "snapshot" integration. This allows stop action analysis of events as short as 2  $\mu$ sec and micro-scanning to produce high-resolution FLIR imagery. It has an indium antimonide (InSb)  $256 \times 256$  FPA, miniaturized electronics, and high reliability linear Stirling cooler, packaged in a portable, full-featured IR camera operating in the 3-to5- $\mu$ m spectral band. The camera specifications are listed as follows:

Detector technology	256 $\times$ 256 InSb
Input power	18V to 32V DC, 50 Watts
Video interfaces	NTSC or PAL, S-video
Dynamic range	65 dB FPA average / 45 dB per pixel
Remote control	RS-422 or RS-232C
Spectral band	3-to 5- $\mu$ m
Cooling method	Stirling closed cycle
NETD	0.025 $^{\circ}$ K average at 23 $^{\circ}$ C
Data interface	Parallel and serial digital
Resolution	12-bits
Video synchronization	External sync input
Dimensions	5.1"H $\times$ 5.7"W $\times$ 6.75"L
Weight	9 lbs max
Temperature range:	
Operational	0 to +50 $^{\circ}$ C (case temperature)
Storage	-54 to +65 $^{\circ}$ C (camera only)

**FOV:**

100 mm EFL lens	4.4°
25 mm EFL lens	17.5°

Galileo's frame rate can vary up to 120 Hz for the full  $256 \times 256$  frame mode, up to 1400 Hz for the  $64 \times 64$  frame mode. Exact frame rate limits are a function of the selected integration times.

## Section 4

### REMARKS AND CONCLUSIONS

A thermal nondestructive workstation is comprised of two main parts; the source of energy that produces the thermal excitation and the thermal imaging system that dynamically collects the thermal data. These components must be perfectly synchronized to increase the probability of detection, maximize contrast, and reduce system's power requirements. This harmonization allows the acquisition of reliable data. This information is then image-processed to characterize the substructure of the material under test.

The thermal imaging system is a vital component of the NDT workstation. It is the part responsible for acquiring the two-dimensional time history of the surface temperature of the sample under test. The IR camera must have both excellent thermal sensitivity and spatial resolution in order increase the probability of detection of subsurface defects and damage in composite structures. The IR imaging system analysis of Section 2, contains the ultimate characteristics needed for this particular type of application. However, the development and cost of such a system is prohibitive for this Phase I. Instead, existing equipment will be used to establish the usefulness of the TNDE method as a non-contact, large area NDI technique. PSR has identified two companies with the necessary equipment to fulfill the Phase I requirements. These vendors are Bales Scientific Inc. (BSI) in Walnut Creek, California and Thermal Wave Imaging (TWI) in Lathrup Village, Michigan.

BSI thermal image processor is a non-portable scanning system with fast optics but slow frame rate. The time resolution is improved by using the line scan mode which continuously scans only one line of data within the field of view. In this way, the temperature data is obtained very fast in time (i.e., 0.555 msec per line) however, a poor signal-to-noise ratio is obtained. The camera contains an IR optical zoom that provides different magnifications and thus system flexibility. This camera was developed at first for medical applications, however, its features are also suitable for TNDE applications.

TWI uses the Galileo configurable infrared camera. This camera is developed by Amber, a Raytheon Company located in Goleta, California. The Galileo is a modular FLIR sensor featuring flexible architecture designed for integration into gimbal payloads and research applications. Operating in the 3-to 5- $\mu\text{m}$  spectral band, Galileo is a high-speed infrared camera with a frame rate that can vary up to 1400 Hz. Nevertheless, at this speed, its FOV is rather small (i.e.,  $4.4^\circ$ ). It also contains a large  $F_\#$  (i.e., slow optics). In other words, this camera was specially developed for applications other than



nondestructive thermography. TWI system is compatible with several other IR cameras (e.g., Inframetrics), nevertheless, none of them have the necessary thermal sensitivity (i.e., greater than  $0.07^{\circ}\text{C}$  at room temperature) for this task.

When selecting an infrared camera suitable for TNDE, one major question arises: "Which atmospheric band is to be selected?" As Planck's law stipulates, low temperature bodies emit more in the long wavelengths; consequently they will be more of interest to observe near room temperature objects. Emitted radiation from objects at room temperature ( $300^{\circ}\text{K}$ ) peaks in the long wavelength range. In the TNDE the temperature rises abruptly to approximately  $450^{\circ}\text{K}$  from room temperature right after the energy source pulse has hit the surface of the sample under test, and then a rapid exponential decay is observed. Therefore, for this type of applications, we could say that the long wave spectral range (8-12- $\mu\text{m}$ ) is more desirable band than the MWIR spectral band (3-5- $\mu\text{m}$ ). However, before this conclusion is made, another consideration must be taken into account. The factor of how much the exitance changes with temperature (i.e., the exitance contrast), is also important to the sensitivity of the infrared system. In this case, the 3-to 5- $\mu\text{m}$  band is where the exitance of the specimen under test changes most with temperature, giving a better thermal sensitivity. Although no specific rule can be formulated, we may point out due to our experience in this field, that better measurements have been obtained in LWIR spectrum band. The specification and characteristics of the TNDE thermal imaging systems mentioned in this report are shown in Table 1.

Raytheon-Amber has developed a new Galileo camera designed for the long wave infrared (LWIR). This Galileo comprises a  $256 \times 256$  snapshot MCT FPA. The detectors are sensitive in the 8.2- 9.2- $\mu\text{m}$  waveband. Because the same focal plane array readout circuit design is used, virtually all aspects of camera form, fit, and function are identical to the standard middle wave infrared (MWIR) Galileo camera. This camera is equipped with a germanium cold-filter and dewar window to transmit infrared energy at the longer wavelengths. A significant cost saving can be achieved for Phase II, if this camera can be implemented in the NDE prototype system. A quotation for a custom LWIR Galileo camera with a F/1.8 coldshield is shown in Appendix A.

The stimulation sources of both BSI and TWI TNDE systems are quite similar. They consist of linear xenon flash-lamps and pulsed-forming networks (PFN's). A programmable power supply charges and regulates all PFN's simultaneously. Parabolic reflectors are located behind each lamp to help direct the energy to the specimen under test. **They are not portable.** These systems are capable of flashing single short

Table 1. Comparison among the thermal imaging systems.

Specifications	Optimum Design	TIP	AMBER
Type	Scanning	Scanning	Staring
Detector configuration	288 × 4 linear array	1 to 4 (2:1 interlace)	256 × 256
Detector material	MCT	MCT	InSb
Detector type	Photovoltaic	Photoconductive	Photovoltaic
Uniformity	N/A	N/A	0.1 % after correction
D*	$1.5 \times 10^{11}$	N/A	N/A
Spectral range	7.7-to 10.5- $\mu\text{m}$	8-to 12- $\mu\text{m}$	3-to 5- $\mu\text{m}$
F/#	1	1.2	2.5
FOV (degrees)	$30^\circ \times 15^\circ$	$30^\circ \times 20^\circ$	$17.5^\circ$ for f = 25 mm
IFOV (mrad)	0.83 x 0.93 for f = 30 mm	1.2 for f = 100 mm	1.2 for f = 25 mm
NETD (mK)	15	50	25
Frame rate (Frames/sec)	500	15-30	120 for 256 × 256 480 for 128 × 128 1400 for 64 × 64
Cost	N/A	\$60,000.00	\$60,000.00

pulses of high energy. The utilization of this technique is very practical when the samples tested are high conductance materials such as aluminum and steel. However, when testing composite structures such as graphite-epoxy (i.e., low thermal conductivity), a train of pulses is more desirable because it increases the sensitivity of the system. PSR is modifying BSI equipment to produce a periodic thermal cycling that best fit the thermal properties of the composite materials under test (i.e., in-fleet composite motor cases/airframes).

If Phase I resources allow, PSR will perform experiments with both BSI and TWI systems.

## **Appendix A**

### **ACRONYMS**

CCD	Charge Coupled Device
FLIR	Forward Looking Infrared
FOV	Field of View
FPA	Focal Plane Array
HFOV	Horizontal Field of View
HIFOV	Horizontal Instantaneous Field of View
InSb	Indium Antimonide
IFOV	Instantaneous Field of View
IR	Infrared
LWIR	Long Wave Infrared
MCT	Mercury Cadmium Telluride
MWIR	Middle Wave Infrared
NDE	Nondestructive Evaluation
NDI	Nondestructive Inspection
NDT	Nondestructive Testing
NETD	Noise Equivalent Temperature Difference
PFN	Pulsed Forming Network
TDI	Time Delay Integration
TIP	Thermal Image Processor
TNDE	Thermal Nondestructive Evaluation
TSI	Thermal Imaging System
VFOV	Vertical Field of View
VIFOV	Instantaneous Vertical Field of View

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## Appendix B

### NOMENCLATURE

$D_{\text{blur}}$	Diffraction limited diameter spot
$D_{\text{opt}}$	Clear diameter of the lens
$D^*$	D-star
$E$	Exitance
$f$	Focal length
$F_{\#}$	F-number
$L$	Radiance
$N$	Number of facets of an optical polygon
$Q$	Inductance
$T_{\text{frame}}$	Frame time
$V_{\text{polygon}}$	Speed of an optical polygon
$v_{\text{scan}}$	Scan velocity
$W$	Number of frames per second
$x_{\text{det}}$	Horizontal detector pitch
$x_{\text{total}}$	Horizontal detector array size
$y_{\text{det}}$	Vertical detector pitch
$y_{\text{total}}$	Vertical detector array size
$\tau_{\text{dwell}}$	Dwell time
$\Delta F$	Electronic bandwidth
$\alpha$	Angular substance
$\omega_{\text{polygon}}$	Rotational speed of the scanner
$\frac{\partial L}{\partial T}$	Derivative of the radiance with respect to temperature

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**Appendix C**  
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**Pacific-Sierra  
Research Corp.**

# Fax

<b>To:</b> Mr. Kurt E. Heidner	<b>From:</b> Dr. Arnold Daniels
<b>Fax:</b> (805) 685-0415	<b>Pages:</b> 1
<b>Phone:</b> (805) 685-0315	<b>Date:</b> April 9, 1997
<b>Re:</b> Galileo camera 8-to 12- $\mu$ m	<b>CC:</b>

☐ **Urgent**    ☐ **For Review**    ☐ **Please Comment**    ☒ **Please Reply**    ☐ **Please Recycle**

● **Subject:** Galileo Camera 8-12  $\mu$ m detector FPA.

Would you please send a quotation regarding the following:

**Custom Galilei IR Camera to include:**

1. 256 x 256 detector configuration:
2. MCT Focal plane array
3. Closed-Cycle Stirling cooler
4. 8-to 12- $\mu$ m spectral range
5. 0.1 % uniformity after correction
6. F/1.8 Optical system
7. Frame rate (Frames/sec):  
120 for 256 x 256  
480 for 128 x 128  
1400 for 64 x 64
8. Video Outputs: RS-170, NTSC, S-Video
9. Digital outputs: HSVB (12-bits/4MHz)
10. Remote interface: RS-232
11. Cables
12. Carrying case
13. 110/220 Volts AC?DC converter

**Please specify the following items using the above characteristics:**

1. FOV
2. Detector pitch
3. D\*
4. NETD
5. Standard lenses that you have for this spectral band
6. Data rate [Mbits/sec]

Sierra-Olympic Technologies, Inc.7262 Calle Real, Goleta, CA 93117Ph: (805) 685-0315; Fx: (805) 685-0415**FAX TRANSMISSION****TO:** Arnold Daniels**TRANSMITTED:** 1 of 4**COMPANY:** Pacific Sierra Research**FAX NO:** (310) 314-2323**DATE:** 4-10-97**CC:****FROM:** Kurt E. Heidner, Phone (805) 685-0315; Fax (805) 685-0415

Dear Arnold,

Enclosed is a copy of the quotation for the custom LWIR Galileo camera that you requested. I have also included a copy of Amber's commercial price list that outlines the pricing for Amber's standard LWIR Galileo and LWIR lenses for your review.

Please feel free to call me at (805) 685-0315 if you have any questions or comments.

Sincerely,

Kurt E. Heidner



Sierra-Olympic Technologies, Inc.  
Representative of ~~Amber~~ IR Products

Sierra Olympic Technologies, Inc.

7262 Calle Real, Goleta, CA 93117  
Ph: (805) 685-0315; Fx: (805) 685-0415

April 10, 1997

Arnold Daniels  
Pacific Sierra Research  
2901 28th St.  
Santa Monica, CA 90405

Quotation Reference Number: PSR/Q/4.10.97

Fax: (310) 314-2323

Subject: Request for Quotation

Dear Arnold,

Sierra-Olympic Technologies, Inc. is pleased to supply Pacific Sierra Research with the following quotation for a Custom LWIR Galileo camera system with various lens options. The Galileo IR Camera is designed for high speed, low back ground target applications. The LWIR Galileo comprises the AE173 256x256 simultaneous integrating MCT FPA integrated into a high reliability, cryo-cooler/dewar assembly, at-dewar electronics, and dedicated signal processing electronics. The AE173 FPA implements a centroid windowing feature, allowing full 256x256 operation, or 128x128, or 64x64 subarrays. In the full 256x256 window the Galileo can run up to 120Hz. When operated in the 128x128 or 64x64 modes the frame rate can be increased to 480Hz and 1400Hz respectively. The Galileo is also capable of having its integration time synchronized to specific events by inputting a master clock. This feature greatly increases the cameras functionality with regards to capturing high speed events. The camera also furnishes composite analog video in NTSC, S-Video, and 12-bit digital data in parallel differential or serialized high-speed formats.

## QUOTATION

ITEM	DESCRIPTION	QTY	UNIT PRICE	EXTENSION
1	<b>Custom LWIR Galileo Camera to Include:</b> <b>Part Number: 503819-08</b> <ul style="list-style-type: none"> <li>• Custom f/1.6 Goldfield (See Note)</li> <li>• 256x256 Snapshot MCT Sensor</li> <li>• Cold Filter installed for 8.2-9.2µm Spectral Sensitivity</li> <li>• Closed-cycle Split Stirling Linear Cooler</li> <li>• Camera Power Supply Range 18V-32V</li> <li>• 110/220V AC/DC Converter</li> <li>• 5.1" high x 5.67" wide x 6.75" deep (when attached)</li> <li>• Weight &lt;9lbs</li> <li>• Video Outputs: NTSC and S-Video</li> <li>• Digital Outputs: HSVB (12 Bit/10MHz) and Serial "Hot Link"</li> <li>• Remote Interface: RS-232</li> <li>• Cables Included: NTSC, Video, S-Video, Power</li> <li>• Shipping/Carrying Case</li> <li>• Bayonet Flange Lens Mount</li> </ul> <b>NOTE: Price Includes \$21,830 for NRE &amp; Special Handling</b>	1	\$171,730	\$171,730

This quotation is valid for 30 days from the above date. All orders are bound by Amber's standard condition of sale. Delivery for the above system will be a maximum of 120 days ARO. Delivery is FOB Goleta, CA. Galileo cameras are covered by a one year or 4000 hours of operation warranty. Extended warranties are also available.

Representatives of Amber IR Products

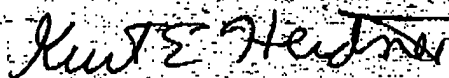
Sierra-Olympic Technologies, Inc.7262 Calle Real, Goleta, CA 93117

Ph: (805) 685-0315; Fx: (805) 685-0415

All contractual actions will be directly between Amber Engineering and the customer. It is understood that Sierra-Olympic Technologies, Inc. is acting only as a representative for Amber Engineering. All contractual matters should be directed to the desk of Ms. Elaine Crandall at (805) 692-1241.

If you have any further technical questions, please feel free to contact me at (805) 685-0315.

Sincerely,  
Kurt E. Heidner



Sierra-Olympic Technologies, Inc.  
Representatives of ~~AMBER~~ IR Products

cc: Ms. Elaine Crandall, Amber Engineering

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Representatives of Amber IR Products

**Raytheon****Domestic Commercial Price List****January 1997****Portable IR Cameras**

<b>503819-13</b>	<b>LWIR Galileo Infrared Camera (NTSC, RS-232)</b>	<b>\$149,900</b>
<b>503819-14</b>	<b>LWIR Galileo Infrared Camera (NTSC, RS-422)</b>	<b>\$149,900</b>

Galileo is a modular IR camera designed for volume-constrained applications, such as gimbals and other stabilized platforms, in addition to stand-alone use. The Galileo comprises the AE173 256x256 Snapshot HgCdTe FPA integrated into a high reliability dewar/cooler assembly, at-dewar electronics, and dedicated signal processing electronics. The HgCdTe detectors are nominally sensitive in the 8.2-9.2 micron waveband. Because the same focal plane array readout circuit design is used, virtually all aspects of camera form, fit, and function are identical to the standard MWIR Galileo camera. The camera is equipped with a germanium coldfilter and dewar window to transmit infrared energy at the longer wavelengths.

The AE173 FPA implements a centroid windowing feature, allowing full 256x256 operation, or 128x128, or 64x64 sub-arrays. The electronics are based on a 3-board set that includes uniformity correction, power, and video. The camera is designed for separation of the sensor engine from the electronics via an interface cable up to ten feet in length. The camera furnishes video in NTSC or PAL format, S-Video, and 12-bit digital data in parallel differential and serialized high-speed formats. LWIR lens options are available.

**Galileo includes:****IR Camera:**

- f/2.5 Optical System
- 256x256 Snapshot HgCdTe Sensor
- 8.2-9.2 micron Coldfilter Typical (Astronomy 'O')
- Linear Split-Stirling Cooler
- Camera Power Supply Range: 18V - 32V
- Size: 5.1" high x 5.67" wide x 6.75" deep
- Weight: 9.6 lbs.
- Video Outputs: NTSC or PAL, S-Video
- Digital Outputs: HSVB (12-Bits/10MHz) and Serial "Hot Link"
- Remote Interface: RS-232 or RS-422

**Accessories:**

- 110/220v AC/DC Converter
- Cables Included: NTSC or PAL Video, S-Video, Interconnect/Power
- Bayonet Flange Lens Mount
- Carrying/Transport Case
- Operating Manual

**Galileo LWIR Lens Options**

<b>250-9044</b>	<b>Lens, 50mm focal length, f/2.3, Ge, bayonet mount</b>	<b>\$12,000</b>
<b>250-9028</b>	<b>Lens, 100mm focal length, f/2.3, Ge, bayonet mount</b>	<b>\$17,500</b>